AIR BAG INTERACTION WITH AND INJURY POTENTIAL FROM COMMON STEERING CONTROL DEVICES

Greg Shaw
Transportation Rehabilitation Engineering Center
Automobile Safety Laboratory, University of Virginia

Gayle Dalrymple and Carl Ragland
National Highway Traffic Safety Administration

ABSTRACT

This study explored the injury potential associated with the use of steering control devices in frontal impacts. Steering control devices, an example of which is the spinner knob, are used by people who have difficulty gripping a steering wheel. These devices typically are clamped to the lower quadrant of the wheel rim and have projections that may extend out toward the occupant up to 14 cm and inward towards the air bag module up to 9 cm. A series of investigations were conducted to determine if the devices would : (1) be propelled off the rim by air bag deployment; (2) compromise air bag performance; and/or (3) cause injury to the driver. The investigations included frontal 48 km/h sled tests, quasi-static load tests, static air bag deployments, out-of-position static air bag deployments, and pendulum tests. Test subjects included the Hybrid III 50th percentile male and Hybrid III 5th percentile female anthropomorphic dummies and a male cadaver. The results indicated that there is little chance of the devices being thrown off the rim by air bag deployment and that the presence of the device had little effect on deployment or air bag performance. In addition, the presence of an air bag reduced the frequency and severity of impacts with the devices. The test results provided ample evidence of the potential of one of the devices, the "tri-pin", to cause severe injury to the chest upon impact.

Steering control devices (SCDs) are used by drivers with reduced ability to grip the wheel rim. SCDs, essentially clamp-on handles, are commercially produced in a variety of configurations to suit the various needs of drivers with upper extremity limitations (Fig 1). A representative from MPD Inc., the largest United States manufacturer of these devices, estimates that 8-10,000 SCDs are sold annually, over 80% of which are spinner knobs (Lynn Ringdahl, personal communication, January 1998). The spinner knob is relatively small compared to the u-grip and tri-pin,

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devices that are designed for use by drivers with more substantial deficits. The tri-pin, designed to capture the hand and wrist, requires no grip strength. Both the u-grip and the tri-pin use vertical projections that extend from 11 to 14 cm perpendicular to the face plane of the wheel. The base of the tri-pin extends approximately 9 cm from the inner surface of the rim towards the wheel center.

The series of studies reported in this paper investigates the potential for injury in a motor vehicle crash due to the presence of an SCD. SCDs were designed to maximize driver function and little or no attention was given to safety in crash situations. The development of SCDs predated the introduction of air bags. We were concerned that the devices, especially the larger ones, would: (1) degrade air bag performance either by tearing the bag or affecting its deployment; (2) be ejected from the wheel rim during air bag deployment; or (3) be impacted by the driver in a frontal collision.

To our knowledge, only one prior study has examined SCD crash safety. This study, conducted by Gayle Dalrymple at the University of Virginia Automobile Safety Laboratory (ASL), consisted of static air bag deployments with seven SCD types [Dalrymple, 1996]. Results of those tests indicated the potential for the tri-pin design to prevent proper air bag deployment.

Interviews with several trauma surgeons and a literature search, primarily of the SAE Index and the Medline data base, failed to produce information that would allow us to predict injury levels for the type of "blunt penetrating trauma" that appeared possible from impacts with SCD projections.

Given the general lack of information regarding injury potential for SCDs, we proceeded with the series of investigations reported here. The ultimate objective of this ongoing work is to determine if these devices represent a significant threat to driver safety and, if so, to recommend strategies to reduce this risk.

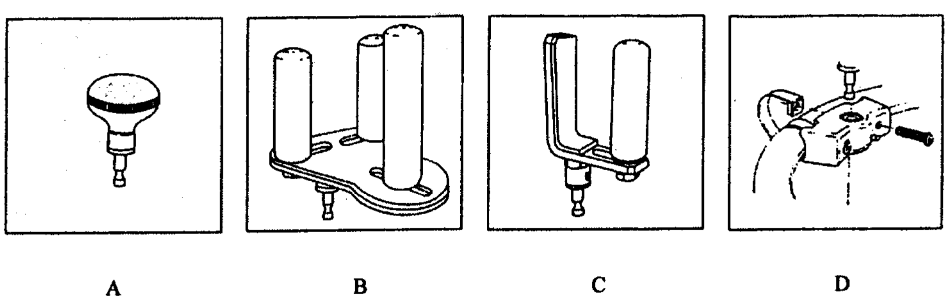


Figure 1. Steering Control Devices (SCDs). A: Spinner; B: Tri-pin; C: U-grip; D: Wheel rim mounting bracket

METHODS

A series of investigations were conducted to determine whether SCDs could cause driver injuries in crash situations (Table 1). These investigations included frontal 48 km/h sled tests, quasi-static load tests, static air bag deployments, out-of-position static air bag deployments, and pendulum tests. Test subjects included a Hybrid III 50th percentile male anthropomorphic dummy, a Hybrid III 5th percentile female anthropomorphic dummy, and a male cadaver.

Table 1. Evaluations of Safety Concerns Related to SCD Use

Investigations	**Sled Tests**	**Quasi-static Load Tests**	**Static Air Bag Deployments**	**Out-of-Position Static Air Bag Deployments**	**SCD – Chest Pendulum Impacts**
# of Tests Conducted	24	41	7	4	17
Devices Tested	MPD① Tri-pin, U-grip, Spinner	MPD② Single Post, MPS Single Post, MPS U-grip	MPD Tri-pin (instrumented)	MPD Tri-pin	MPD Tri-pin (instrumented)
Safety Concern:					
Ejection of device by air bag deployment	X		X		
Effect on air bag performance	X		X	X	
Injury by impact with device	X	X			X
Injury due to proximity to the air bag necessitated by SCD use				X	

Notes:
① MPD – Mobility Products and Design (MPD/Crow River) Inc. Brooten, MN.
② MPS – Manufacturing and Production Services Corporation, San Diego, CA.

SLED TESTS – Sled testing consisted of twenty-four 48 km/h simulated frontal impacts conducted on the sled at the ASL [Pilkey at al, 1996]. The sled tests were conducted using an instrumented male Hybrid III 50th percentile dummy seated in both a buck configured to approximate a 1992 Ford Taurus and a buck simulating a 1992 Ford E150 van (Fig. 2). Baseline tests, run without an SCD, preceded tests in which the SCDs were fastened to the steering wheel rim with metal bands at the 5 o'clock position. In two tests that simulated the driver turning the wheel, the SCD was placed at the 12 o'clock position. Tests were conducted with occupant restraint belts only and with both belts and air bag.

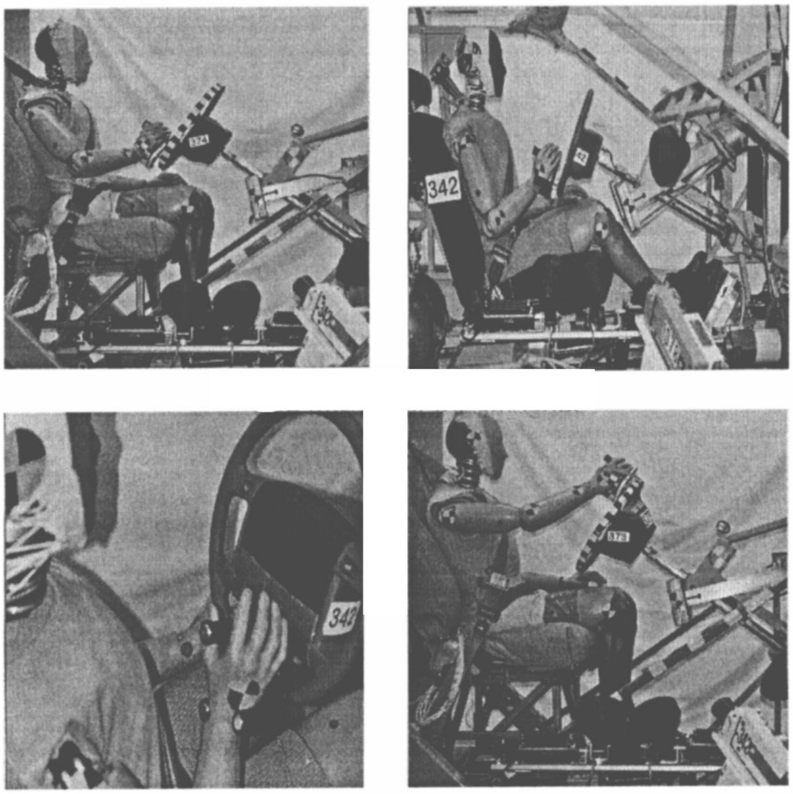


Figure 2. Test Set-Up for the Tri-pin Steering Control Device: **(A)** the Taurus buck; **(B)** pre-test hand position; **(C)** the E150 van buck with the hand in the 5 o'clock position; and **(D)** the E150 van buck with the hand in the 12 o'clock position.

QUASI-STATIC LOADING TESTS - Forty-one tests involving axial, quasi-static loading of SCDs installed on steering wheel rims were conducted to determine the maximum force that could be exerted on the driver in a frontal collision [Pilkey et al, 1996]. Test configurations were chosen to explore the range of device installations currently in use. Test variables included SCD type (Single Post and U-grip), SCD mounting strap installation torques (four levels), and steering wheel rim hardness (three levels represented by Ford, Pontiac, and Dodge wheels).

The tests were conducted on a Tinius Olsen static test machine. The machine cross head was lowered under computer control at a rate of 25 mm/min up to a displacement of 50 mm, at which point it was stopped. The force and displacement data were recorded. The steering wheel was mounted vertically to a simulated steering column. The SCD pin was loaded by a large, flat indentor faced with a Teflon sheet to reduce the effects of forces that were not normal to the direction of displacement (Fig. 3).

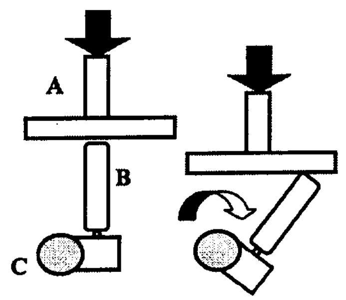


Figure 3. Set-up for the quasi-static testing of the steering control devices. Rotation of the mounting clamp on the steering wheel rim was the force-limiting factor in most of the tests. A – Indentor, B – Single post SCD, C – Cross section of the steering wheel rim.

STATIC AIR BAG DEPLOYMENT TESTS - Seven air bags, representative of different configurations in current production, were deployed to determine the effects of the deployment on the tri-pin SCD and the effects of the device on deployment of the air bag. The primary concern was that the deploying air bag would generate sufficient force to propel the SCD off the rim. Air bag aggressivity measures (60 liter tank test) ranged from a low of 6 kilopascals/ms rise time for the 1992 Honda Civic airbag to a high of 11 kilopascals/ms rise time for both the 1991 Mercury Marquis and 1994 Mercury Sable airbags. The test set-up included an instrumented tri-pin SCD (Fig. 4) mounted on production steering wheels. A tri-pin was chosen because it represents the largest commercially available SCD and the one most likely to interact with the air bag.

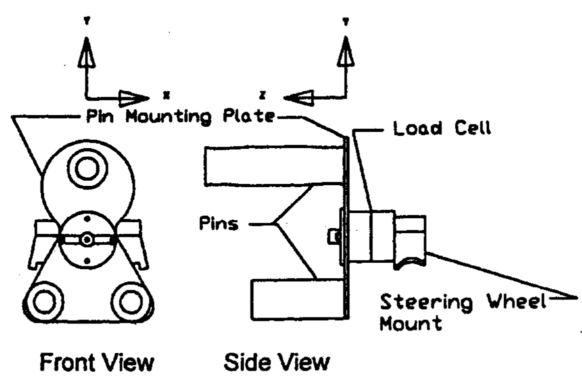


Figure 4. Instrumented Tri-pin SCD. A Denton (Robert A. Denton Inc., Rochester Hills, MI) model #1584 lower tibia 3-axis load cell replaced the OEM aluminum block under the pin mounting plate. Modifications to the OEM tri-pin to accommodate the load cell placed the pins 20 mm farther above the wheel rim and 3 mm closer to the wheel center.

OUT –OF- POSITION STATIC AIR BAG DEPLOYMENTS - Four air bags were deployed to determine the injury potential of the deployment on the chest and neck of the 5th percentile female Hybrid III dummy and the effects of the device, an MPD tri-pin, on the deployment of the air bag. The primary concern was that the deploying air bag would generate sufficient force to cause injury if the driver was closer than the National Highway Traffic Safety Administration (NHTSA) - recommended 254 mm (10”) from the wheel [National Highway Traffic Safety Administration, year].

The test set up included an MPD tri-pin SCD mounted on a production steering wheel rim at the 5 o’clock position (Fig. 1). Test variables included air bag type (Ford E150 1992 and 1998 (depowered)), and driver position. A driver evaluator/occupational therapist helped to define the smallest chest-to-wheel sitting position utilized by 95% of small drivers who use tri-pins. Tests were conducted at this position in which the horizontal chest-to-wheel center was 245 mm (9.6”), and at two alternate positions (Fig. 5). The nearest “worst case” position, 182 mm (7.2”), was chosen to simulate a driver who required a 20 mm nearer sitting position and who had moved (43 mm) closer to the wheel due to pre-impact braking. At this position, the dummy was leaning against the tri-pin. The third position, 305 mm (12”), was chosen to collect data at a position considered to minimize air bag related injury.

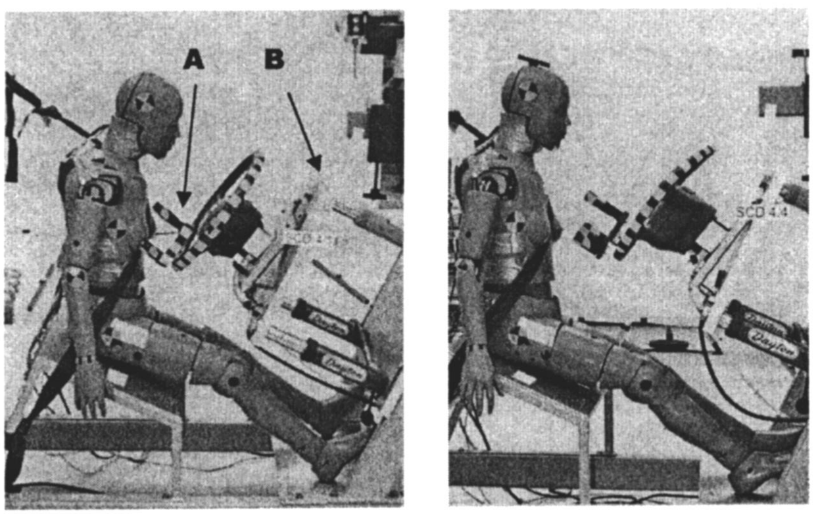
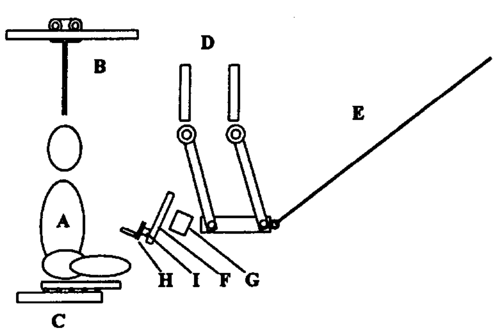


Figure 5. Test Set-Up. The left photograph shows the closest dummy position relative to the air bag (Test 4.1). A: Steering control device; B: Adjustable steering wheel mounting frame. The right photograph illustrates the rearmost dummy position used in Test 4.4.

PENDULUM TESTS - We developed a pendulum test to simulate the case of the driver impacting an SCD in a frontal collision without an air bag. In these tests, the short pin of the tri-pin device was mounted to a steering wheel rim which, in turn, was installed on the front face of the pendulum impactor (Fig. 6). Sled test results indicated that one of the short pins nearest the dummy's chest caused the highest contact pressures. Similar results were recorded for the cylindrical U-grip pin that is similar in height and position to that of the tri-pin short pin. The stationary subject was seated in the path of the SCD pin so that the pin impacted the chest.

In a series of 11 tests, the effective mass and impact velocity of the pendulum were gradually increased in order to approximate the most severe impact seen in the sled test series. Fuji film (*Fuji Prescale Film, Fuji Photo Film Co, LTD. Tokyo, Japan)* image density, film "cratering", and steering wheel deformation were the parameters used to adjust the pendulum impact.

Tests 3.1 and 3.2 were conducted using a single cadaver. In Test 3.1, the lower right ribcage was impacted with the SCD pin; in Test 3.2, the upper left ribcage was impacted. The one cadaver used in this testing series was chosen to be as similar as possible to the 50th % male dummy. The cadaver test subject was a 44 yr. old Caucasian male of average height (172 cm) and build.



A - Test subject. Dummy tests used a Hybrid III 50th percentile male with a string potentiometer chest, chest slider, chest triaxial, and sternum single axis accelerometers. Sandwiches of low, medium, and high range Fuji Prescale pressure sensitive film was taped to the chest prior to each test. **B** - Overhead suspension system with hoist and track. **C** – Sliding seat. **D** - Impactor and suspension members of the UVA compound pendulum. **E** - Decelerator strap – 7% elongation Dacron seat belt webbing 340 cm total length. **F** - 1992 Ford E150 van steering wheel. **G** - Denton model # 1765 5-axis steering wheel load cell. **H** - Instrumented tri-pin SCD with one lower short pin. **I** – Denton model # 1584 3-axis lower tibia load cell.

Figure 6. Pendulum Test Set-Up. A translating positioning system was used to approximate the inverse of the inertial forward movement of the dummy torso in the sled tests. The test subject was positioned in a sitting posture atop a seat surface (C) that could translate backward at least 15 cm (6"). An overhead suspension chain (B) also held the subject in position. The chain hoist was on a track that allowed backward movement of the subject.

RESULTS

SLED TESTS SERIES - At no time did the SCD become disengaged from its mount nor was the mount permanently displaced from its initial position on the steering wheel rim. The SCDs did not tear or abrade the air bag fabric.

According to NHTSA's guidelines for interpreting frontal crash test dummy instrument data (49 CFR 571.208), the surrogate driver would have had a low probability of sustaining life-threatening head or chest injury for any of the simulated collisions in this test series. However, dummy impacts with the u-grip and tri-pin showed the potential to cause localized damage to the ribcage and the face. Impacts were more severe in belt-only tests conducted using the van buck. In five of these tests, the chest or the head came in contact with the SCD generating high localized pressure. Eight SCD contacts (hits) were recorded in four of the tests. The hardest hits occurred in belt-only Test Runs 369 (tri-pin 5 o'clock), 373 (tri-pin 12 o'clock), and 370 (u-grip) and in the belt and air bag Test Runs 374a (tri-pin 5 o'clock) and 375 (u-grip) (Fig. 7). Chest-mounted Fuji film recorded contact pressures that exceeded the film's upper range of 980 N/cm^2. Peak pressure due to loading by the shoulder belt was estimated to be 275 N/cm^2. In Test Run 370, the most severe impact occurred, sufficient to "crater" the Fuji film (Fig. 8). Evidence corroborating Fuji film records of high pressures included greater chest deflection and greater permanent deformation of the steering wheel rim. In Test Run 373, contact with the tri-pin was sufficient to tear both layers of chamois above the dummy's left eye and to break the tri-pin base.

QUASI-STATIC LOADING TESTS - In the series of 41 quasi-static tests, the maximum normal load exerted by the pin of various SCDs ranged from 180 to 1600 N, with four tests resulting in loads exceeding 1000 N. In several of the tests, the wheel rim deformed substantially before the device rotated about the rim. In one case, the 50 mm deformation was due largely to rim deformation.

STATIC AIR BAG DEPLOYMENT TEST - The air bag exerted a maximum force along the axis of the mounting pin of 2103 N in Test 1.7 (Table 5.). As was observed in the sled tests, the tri-pin partially blocked the bags during the first 10-25 ms after firing. After about 25 ms, the bag, when viewed from the front, was symmetrical if somewhat displaced upward and away from the SCD. No air bag tears or abrasions were observed.

Location Key

	Chest Potentiometer Attachment Locations	X cm	Z cm
UR	Upper right	5	31
UL	Upper left	-5	31
LR	Lower right	5	16.5
LL	Lower left	-5	16.5

	SCD Impact Locations	X cm	Z cm
A	Tri-pin upper pin; 373	-3	60
B	U-grip post; 375	4	23
C	Tri-pin lower left pin; 374	5	19.5
D	Tri-pin lower right pin; 369	9	17
E	U-grip post; 370	1.5	18

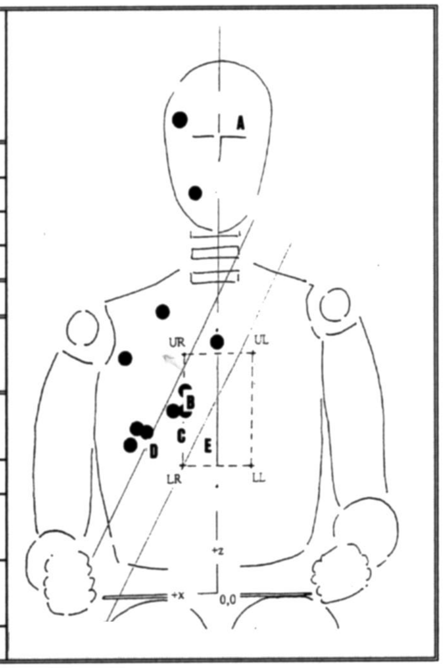


Figure 7. Dummy / SCD pin Impact Location Summary for Both the Taurus and Van Sled Tests. All of the impacts occurred with either the tripin or u-grip. All of the most severe impacts, labeled A-E, occurred in the van buck series. An impact was considered "severe" if the image recorded on the Fuji film was obviously darker than that produced by the shoulder belt.

Figure 8. In Test Run 370 (belt -only u-grip), the crater in the Fuji film suggested purely axial loading by the pin. In tests that produced less intense images, the pin moved relative to the chest.

Table 5. Maximum Recorded Values for Air bag Loading of SCD.

	Fx		Fz		My	
Direction of Action on the SCD	Force pushing the SCD toward the wheel center.	Force pushing the SCD away from the wheel center.	Force tending to eject the SCD upward.	Force tending to drive the SCD downward.	Moment causing downward rotation.	Moment causing upward rotation.
Maximum Recorded Values	1659 N 373 lbf	-1057 N -238 lbf	2103 N 472 lbf	-837 N -188 lbf	58.4 N-m 43.1 Ft-lb	-40.1 N-m -29.6 Ft-lb
Test # Air Bag	1.7 1994 Mercury Sable	1.3 1992 Ford E150 Van	1.7 1994 Mercury Sable	1.4 1992 Honda Civic	1.1 1992 Ford E150 Van	1.7 1994 Mercury Sable

OUT-OF-POSITION STATIC AIR BAG DEPLOYMENTS - No configuration in this test series produced instrument values suggesting likelihood of injury. A maximum value of 835 N for neck tension, 19.1 N-m neck extension moment, and 12 g chest resultant acceleration were recorded in Test 4.2, the test which included the most aggressive air bag and the closest sitting position (Table 6). All values were less than half of currently accepted or proposed injury threshold levels [Mertz et al, 1997]. Instrument values were much lower in Test 4.1, in which the depowered air bag was used. In Tests 4.2 through 4.4, most instrument values were reduced as the dummy was moved farther away from the air bag module. Most values for the fully powered air bag dropped below those recorded in Test 4.1 once the dummy had been moved a distance of 305 mm (12") from the wheel (Test 4.3).

Table 6. Selected Peak Sensor Values.

Test #	Configuration	Chest-to-wheel mm / in	Neck Tension N	Extension Moment Y axis N-m	Resultant Chest Accel. g
4.1	Depowered air bag; Pre-impact braking position	182 / 7.2	361	-9.4	6
4.2	Pre '98 aggressive air bag: Pre-impact braking position	182 / 7.2	835	-19.1	12
4.3	Pre '98 aggressive air bag: Close driving position	245 / 9.6	663	-14.8	6
4.4	Pre '98 aggressive air bag: Close driving position + 60 mm.	305 / 12	311	-4.9	3

PENDULUM TESTS SERIES - The calculated resultant force of the tri-pin device pin on the subject chest averaged 1233 N for the cadaver tests and 2472 N for the dummy tests in which the momentum of the pendulum approximated that of the dummy in the sled tests (Table 7). Upon impact with the chest, the SCD rotated toward the steering wheel center, springing back to within 5 to 10 degrees of its original orientation. In all cases, the lower rim of the steering wheel was permanently deformed 4 to 10 mm.

Cadaver injury was determined by autopsy after the conclusion of the chest wall impacts. Injuries included six rib fractures in the lower right quadrant attributed to Test 3.1 and five fractures in the upper left quadrant attributed to Test 3.2 (Fig. 9). The most severe injuries involved tears in the musculature and fascia of the chest wall that suggested a high probability of a pneumothorax, which is considered a serious injury (Abbreviated Injury Scale (AIS = 4) [Association for the Advancement of Automotive Medicine, 1990]. No evidence of impact injury was evident in the underlying organs, such as the liver.

Table 7. Pendulum Tests Results Summary.

Test Series①		Test #	SCD Peak Load Cell Fx (N)	SCD Peak Load Cell Fz (N)	SCD Load Cell Fx-Fz Resultant (N) ②	Peak Contact Pressure (Kg/cm^2) ③	Lower Right Chest Deflection (mm)	MAIS
Dummy	A	2.13	770	-2351	2474	-	44.61	NA
		2.16	855	-2325	2470	500–1300	49.71	NA
Cadaver	B	3.1	774	-1236	1457	500–1300	NA	4
		3.2	708	-727	1010	-	NA	4

Notes:
① *Dummy Series A* – Replicate tests at the targeted impact severity; approximated the most severe impact seen in the sled test series (Test Run 370: U-grip).
Cadaver Series B – Tests at the targeted impact severity. In Test 3.1, the pin impacted the lower right chest. In Test 3.2, the pin impacted the upper left chest.
②Fx – Fz resultant approximates peak pin contact force with chest.
③Peak contact pressure range estimated from Fuji film image.
NA – Not applicable.

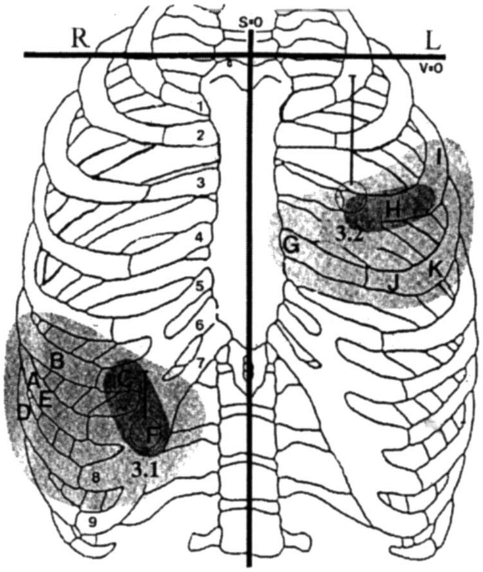


Figure 9. Summary mapping of rib fractures for Tests 3.1 and 3.2. The darker shaded areas indicate severe damage to the chest wall estimated to result in an AIS 4 injury [AAAM, 1990]. The capital letters indicate fractures. Fracture sites were measured down from the jugular notch (V = 0) and over from the sternal centerline (S = 0). Fractures A and D are more lateral than indicated. Impact sites lie at the center of the two circles which are labeled with test numbers. The lines above the impact sites indicate the centerline of the pin contact area. After the contacting at the chest at the impact site, there was upward movement of the pin relative to the chest due to pendulum movement and rotation of the SCD about the wheel rim.

Rib Fracture Key

	Rib #	V ① (cm)	S ② (cm)	Fx Type ③	I.D.	Comment
R	7	14.8	15.2	FP	**A**	Periostial tear.
	6	15.5	11.7	FP	**B**	
	6	17.5	7.5	D, CC	**C**	Displaced significantly. Tear in pleural lining.
	8	22.0	14.0	FP	**D**	Periostial tear.
	7	19.0	12.0	FP	**E**	Periostial tear.
	7	21.0	6.0	D, CC	**F**	Near hard pin impact site. Tear in pleural lining.
L	4	10.1	1.4	FP	**G**	At junction with sternum.
	3	5.5	8.2	FP	**H**	Periostial tear.
	3	3.0	12.6	D	**I**	Tears of muscle and fascia on both sides of rib.
	4	10.0	7.7	FP	**J**	
	4	7.0	10.7	FP	**K**	

Notes: ① V – Vertical distance down from the jugular notch. ② S – Lateral distance from chest centerline. ③ Fracture Code Key **FP** – Simple fracture; periosteum is lacerated. **C** – Comminuted fracture. The affected bone is in more than two pieces. **CC** – Costechondral fracture. **D** – Displaced fracture.

DISCUSSION

Concerns that the presence of an SCD would degrade air bag performance or that the SCD would be thrown off the wheel during bag deployment were not realized in either the sled test series or the static air bag deployments. The SCDs caused no abrasions or cuts to the air bag fabric. The lack of device ejections and lack of air bag damage were consistent with the findings of the Dalrymple (1996) study. When considering when to recommend air bag use with SCDs, the remote possibility of SCD ejection is overshadowed by the well-documented benefits of air bag use. Test results did not support concerns regarding injuries due to the air bag itself for SCD users who must sit closer than the recommended 245 mm (10") from the air bag.

While the test results dispelled concerns regarding dangerous air bag and SCD interaction, the results, especially those from the cadaver tests, provided ample evidence that chest impacts with certain types of SCDs could cause severe injury. The contact loads generated by the u-grip and tri-pin devices were sufficient to break ribs and cause facial injuries. In the quasi-static test series, four tests produced loads exceeding 1000 N. AIS 4 injuries (severe fractures and tearing of the chest wall) were observed in the cadaver pendulum tests. Damage to the ribcage due to the SCD pin was greater than the injury due to shoulder belt and air bag loading in 50-56 km/h frontal impact tests. In such tests, rib fractures are a common occurrence. Peak dynamic loading by the SCD pin ranged from 1010 to 1460 N.

In addition to the demonstrated potential for chest injury, the results suggested a strong potential for eye and facial injuries. Facial impacts with the SCD may occur in a frontal collision as the driver is executing a turn or uses a device mounted on the upper half of the wheel rim.

It should be noted that only the u-grip and tri-pin devices posed impact injury potential. The less commonly prescribed single post device is of similar geometry and could present a similar injury risk. No significant contacts occurred in the sled tests when the spinner knob was used. This small, low profile SCD is the most commonly used steering assist.

When using the results of this test program to evaluate the risk of injury to drivers with disabilities, one must note that both the sled and pendulum tests represent, as do other automotive compliance tests, a 48 km/h frontal impact with a rigid barrier, a severe and relatively rare event. On the other hand, these tests - simulating a driver's chest at a moderate distance from the steering wheel and with a carefully positioned shoulder belt - probably do not represent worst case impact scenarios. Minor variations in how quickly the shoulder belt arrests forward trunk movement could substantially affect SCD impact severity. An increase in shoulder belt slack would increase SCD impact loads. The relatively robust rib cage integrity of the young cadaver test subject also likely limited the extent of the observed injuries and suggests that real world drivers, who are more frail, would suffer more severe injuries from a similar impact. Although we feel that certain SCDs represent an injury risk, there have been no documented cases of driver injury. However, because relatively few drivers use these devices, this lack of inquiry data is not unexpected.

OTHER OBSERVATIONS - While no SCD ejections were observed, in some tests there was evidence of substantial loading by the air bag and air bag cover flap acting to dislodge the SCD from its mount. The current method of attaching the SCD grip to the steering wheel for most designs is to capture a pin on the base of the grip in a mounting bracket secured to the steering wheel rim with flexible metal bands similar to automotive hose clamps (Fig. 1). Given this method of attachment, the primary means by which an air bag could eject an SCD from its mounting bracket would be to exert a force along the axis of the mounting pin. In one sled test, the tri-pin mounting shaft was pulled upward 6 mm presumably due to an insufficiently tightened set screw. However, static deployments of air bags with inflator parameters similar to those of the increasingly common depowered air bags produced substantially less force on the SCD.

The results of the static air bag deployment tests included a wide range of loads that would push the SCD up and out of its mount (+Z axis of the SCD load cell). Peak recorded loads ranged from 442 to 2126 N. The results suggested a relationship between air bag type and peak SCD loading. The highest recorded load (2103 N (472 lbf)) was recorded during the test of the standard 1994 Mercury Sable air bag. The 1992 Honda Civic air bag recorded the lowest + Z loading of 442 N (99 lbf). These results parallel tank test data that indicated that the 1994 Sable air bag was the most aggressive and that the 1992 Civic air bag was the least aggressive. In general, there appeared to be a positive relationship between tank test aggressivity measures and SCD loading for air bags with conventional deployment patterns. The anticipated industry-wide use of depowered air bags, with aggressivity metrics similar to that of the 1992 Civic, promises to reduce the probability that the SCD would be heavily loaded.

The study results raise concerns regarding the crashworthiness of other adaptive driving equipment. Remote, zero effort steering wheels, hand controls, secondary control panels for lights and turn signals, and other adaptive equipment are often mounted very close to the driver. In some cases, remote steering wheels are in front of the OEM air bag-equipped wheel.

CONCLUSIONS AND RECOMMENDATIONS

The development of steering control devices to assist drivers with disabilities predated the introduction of air bags. The size and shape of the devices evolved without apparent considerations of crash safety. Despite these facts, concerns that the devices would compromise air bag performance and that they would be ejected from the steering wheel rim were not realized in this test program. However, the concern that the driver may be injured when thrown into the SCD during a frontal collision was supported by the test results. U-grip and tri-pin SCDs, both fabricated with projections extending toward the driver, were capable of generating substantial loading to the chest and face. Cadaver subject rib cage injuries were classified as severe.

We recommend that SCDs such as the u-grip and tri-pin be redesigned to reduce their impact injury potential. Toward this end, we have begun a design development and testing program to establish design criteria for a crash safe SCD that does not compromise device function.

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